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Title Probabilities of Turkey Carcase Spoilage through Temperature and Surface Moisture Effects during pre-Christmas Storage Periods.

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Abstract

This memorandum examines the limitations imposed by climate on producers of farm fresh, dry plucked, unevicerated turkeys. Typical pre-Christmas storage periods are selected and the probabilities of encountering high seasonal temperatures are calculated. The likelihood of periods of condensation are assessed from measured relationships between skin and ambient temperatures, in conjunction with hourly weather records over a number of years. The implications of condensation on the skin are discussed with respect to the keeping quality of the turkey carcase. Finally the benefits to be gained from fan ventilated stores are considered.

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Introduction

Producers of farm fresh Christmas turkeys, in the absence of refrigeration, must operate within the limits imposed by the local climate. Temperature is the main constraint, with slaughter and plucking followed by storage in ambient conditions commencing around the 8-10th December. In warm seasons this can lead to a rapid multiplication of spoilage bacteria and a less than perfect product. A complicating factor is the state of the carcase skin. Microbiologically, a cleanly plucked bird with an unbroken dry skin will have the best keeping quality. Surface moisture on the skin leads to more rapid bacterial growth.

The non-linear dependence of bacterial growth on temperature has been well established under laboratory conditions (ie Farrel and Barnes, 1964), and the general relationship developed by Ratkowsky et al (1982), which was derived from 43 bacterial strains states:

$$r = b\,(T - To)$$

where r = growth rate constant T = temperature

b = regression coefficient To = "conceptual temperature"

To varies depending on the bacterial culture and for pseudomonas spp it is 265K, but it is of no "metabolic significance."

Mead (1985) reviewed the principles of relating an accumulated temperature function to the shelf life of poultry meat and described a time-temperature function integrator which expresses the remaining shelf life in the terms of equivalent days at $0^{o}C$.

Less well reported are the effects of surface moisture caused by fluctuating temperatures on hanging birds. Hall (1986) suggests that refrigerated fresh meat should be kept within a range of 80-85% relative humidity, with the implication that storage at higher humidities will increase rates of spoilage.

This memorandum examines the following aspects during the storage period:

1. Average and extreme pre-Christmas temperatures
2. Frequency of condensation due to fluctuating temperatures
3. Effects of fan ventilation on surface moisture.

1. Average and Extreme pre-Christmas Temperatures

An initial investigation into the effects of temperature on the spoilage bacteria Pseudomonas spp. was carried out between the 11-20 December 1985 in the Midlands by Karn et al (1986). In this study the simplifying assumption was made that the relationship between temperature and generation times for Pseudomonas spp. was linear over the temperature range normally recorded at this time of year, 2 to 10°C. After summing the daily mean skin surface temperatures, above an arbitrary base of 0°C, a total of 86°C days was seen to correspond with levels of spoilage of 10^8 pseudomonas colonies per gram of skin: near to the upper limit for human consumption. Over the same period the accumulated ambient air temperature at an official meteorological site, situated 4 km from the storage building, recorded a total of 75°C days. This indicates that ambient temperatures were broadly similar to those inside the continuously ventilated store.

The 1985 study happened to coincide with an unusually warm pre-Christmas spell, with daytime temperatures often exceeding 10°C. The long term average temperature around this time is 3½ to 4°C. Table 1 shows annual accumulated temperature totals for typical storage periods. The total of 86°C days recorded during 10-20 December 1985 is higher than any year except 1971, with 1977 also worthy of note. Over the longer storage periods, 6-20 Dec and 8-20 Dec totals of 75°C days are frequently exceeded, as can be gauged more readily from table 2 which gives totals for different return periods. For example between 6-20 Dec a total of 81°C days may be expected once every 4 years and between 10-20 Dec a total of 73°C days once every 10 years etc. From this table the marginal nature of storing poultry meat in ambient conditions can be studied. The critical level suggested of 75°C days*, if exceeded more than once in 10 years, may have a higher than acceptable frequency of occurrence. Thus storage between 10-20 Dec is satisfactory, while the longer periods indicate that there will be a requirement for additional cooling.

No measurements of relative humidity or carcase surface moisture were made during this study, but the store was continuously ventilated, producing measured air speeds of between 0.5 m/s and 1.0 m/s.

*The critical level will be lower for wet plucked and/or eviscerated birds.

Table 1.

Accumulated Ambient Temperatures above 0°C for pre-Christmas Periods: °C days West Midlands.

	6-20 Dec	8-20 Dec	10-20 Dec	12-20 Dec	14-20 Dec
1961	62.5	60.4	51.3	31.1	12.8
62	-	-	-	-	-
63	30.5	24.9	19.6	14.3	9.1
64	67.3	48.2	31.0	19.4	4.9
65	81.1	75.5	64.6	55.1	42.5
66	84.9	74.6	63.1	53.3	42.7
67	36.5	32.6	32.6	30.8	20.4
68	39.2	33.0	29.7	25.5	20.6
69	45.9	38.9	30.5	21.0	15.3
1970	73.7	63.2	59.3	50.8	40.7
71	115.3	103.8	93.7	77.5	60.2
72	86.4	73.4	66.7	57.0	39.0
73	70.7	57.5	48.7	41.1	29.8
74	91.8	73.4	58.0	50.9	42.9
75	49.5	34.1	30.5	23.1	19.1
76	25.4	20.2	12.5	10.4	6.5
77	92.1	86.4	74.1	58.0	41.0
78	68.1	64.0	49.4	27.6	12.5
79	81.4	65.9	46.7	33.1	22.5
1980	76.8	74.0	69.5	52.2	33.6
81	12.0	3.6	3.3	3.3	2.8
82	53.3	48.6	39.7	33.6	31.3
83	60.0	54.8	42.7	41.5	36.3
84	64.5	51.1	43.9	36.0	30.7
Mean	63.9	54.9	46.1	36.8	26.8
SD (n-1)	24.7	23.4	21.2	18.0	15.2

Table 2.

Accumulated Air Temperature above 0°C Totals for Different Return Periods: °C days

	1985 Total	Return Period - Years				
		4	6	8	10	20
6-20 Dec	105.5	81	87	92	95	105
8-20 Dec	91.8	71	77	82	85	93
10-20 Dec	85.8	60	66	71	73	81
12-20 Dec	79.2	49	54	57	60	66
14-20 Dec	63.5	37	41	44	46	52

No references could be found to explain the consequences on pseudomonas generation times of surface moisture condensing from the atmosphere onto the skin surface. However, results from a second and more comprehensive ADAS study in the Midlands during November and December 1986 (Binstead et al, 1987), where relative humidity and skin surface moisture levels were also measured, indicated that higher moisture levels compensated for lower storage temperature. The generation times in a relatively warm (c 9°C) but dry ambient air store were not immediately increased when the turkeys were transferred into a cold cabinet (c 2.5°C) in which continuously moderate levels of surface moisture were recorded (RH 90-95%): see fig 1.

It is thought that bacterial multiplication was not noticeably altered on transferring the carcases because the higher humidity may have rehydrated the skin tissues, encouraging bacteria to grow. Indeed it was difficult to visually distinguish between wet and dry pluckled birds in the cold store.

These observations can be further explained by considering the loss and gain of moisture from the carcase during cooling and storage, which in turn will affect the availability of moisture to the bacteria (which they require for growth). The availability of water is usually expressed as the water activity (A_w), the ratio of the equilibrium aqueous vapour pressure of the skin surface to that of pure water at the same temperature (Scott, 1957). The bacteria of importance to meat have no xerotolerance.

During cooling, water evaporation from the warm carcass reduces the A_w at the skin surface to below that required for bacterial growth. Water loss is likely to be greatest over the thickest area of tissue where cooling is slowest since Scott and Vickery (1939) found this to be true for beef carcases. The external temperature is not expected to be critically important, as even at high ambient temperatures Wilhelm et al (1982) noted that dessication prevented bacterial growth for some hours on beef sides. Cooling should be complete within 24 hours to reduce evaporative loss, but should not be too rapid to reduce the risk of cold shortening which toughens the meat.

When the carcase has cooled, surface tissues will rehydrate although fat tissue will remain dry unless the humidity is very high. Hicks et al (1955) and Nottingham and Wyborn (1975) noted that a lag of at least 24 hours can be anticipated before bacterial growth commences with uncontrolled moderate ambient temperatures, provided that evaporation is not restricted by close packing or wrapping carcases in water-impermeable film.

Surface drying can be maintained indefinitely with suitable adjustmets of air speed and humidity, but weight losses may soon become unacceptably high as observed with beef (Law and Vere-Jones 1955). Grey (personal communication) has observed weight losses of 3% moisture from carcases held unwrapped at $-2^{\circ}C$ (just above the freezing point of the meat) for 30 days. Carcases held at $-1^{\circ}C$ for a similar length of time in loosely tied bags lost very little moisture. Unfortunately the relative humidity of the store air in these experiments is not known. From personal observations the authors have also noted severe surface defects such as blistering due to carcases being held in the direct draught of refrigeration units for too long.

The conditions that will slow down bacterial growth and thus give a long shelf life without unecessary weight loss will be $-2^{\circ}C$ to $0^{\circ}C$ at 80-85% R.H. At minus $2^{\circ}C$ extremely accurate refrigeration is required to prevent the meat freezing. It may be more economical to aim for $0^{\circ}C$ and have plus $2^{\circ}C$ as the maximum temperature, only having minus $2^{\circ}C$ if long term (more than 14 days) storage is required.

In an uncontrolled environment, dictated by the local climate, there will be a risk of excessive surface moisture from condensation.

2. **Frequency of Condensation due to Fluctuating Temperatures**

Condensation in an ambient air store will occur due to fluctuating temperatures rather than strong radiative heat exchanges. Previously unreported measurements from the 1985 study revealed that there was a time lag of 1 to 2 hours between changing air and skin surface temperatures in the continuously ventilated store. This time lag increased to 2-3 hours for wing muscle temperature and 6-7 hours for deep intestine temperatures: see fig 2.

Condensation will occur from ambient air it if comes into contact with a surface which is at or below the dew point temperature of the air. It follows that, given a 2 hour time lag between air and skin surface temperature, during a period of increasing ambient temperature the skin surface temperature will be below the air temperature, and at times also below the dew point of the air (ie a "condensation hour").

Table 3 presents one such occasion from Gatwick, Sussex (near to a second trial site) during 1986 and fig 3 illustrates a further example from Elmdon, West Midlands during 1984.

Table 3. Condensation Risk on Carcase Skin: Gatwick 7 Dec 1986: °C

Hour	Air Temperature	Dew Point	Simulated Skin Temperature
0300	0.1	-0.5	-
0400	1.2	0.1	-
0500	3.1	1.3	0.1*
0600	3.6	1.5	1.2*
0700	4.9	3.2	3.1*
0800	5.5	3.6	3.6*
0900	5.9	4.3	4.9
1000	6.6	5.4	5.5

*Skin temperature at or below dew point, therefore condensation will occur.

The frequency of occurrence of periods of condensation will vary both from place to place and also between years. An analysis of "condensation hours" was performed on data from two hourly recording met.sites, Elmdon and Gatwick during 6-24 Dec 1986, and for several earlier years at Elmdon: see table 4.

Table 4. Daily Totals of "Condensation Hours" in December

	Gatwick	Elmdon					
Day	1986	1986	1985	1984	1983	1982	1981
6	4	4	3	0	2	7	0
7	8	3	0	0	3	11	1
8	0	2	7	4	2	0	2
9	0	0	10	1	0	4	2
10	5	4	19	0	0	0	1
11	0	3	6	2	7	0	7
12	7	4	4	19	7	2	4
13	2	3	0	4	1	4	17
14	4	2	0	8	0	10	1
15	10	6	0	10	1	0	0
16	0	0	0	7	4	0	4
17	7	1	0	5	4	0	3
18	0	0	0	0	6	0	3
19	0	0	0	1	4	6	3
20	0	0	0	2	4	0	0
21	0	0	0	0	0	0	0
22	0	0	0	3	6	1	0
23	0	0	0	0	2	7	9
24	2	0	12	0	10	8	5
Total	49	32	61	66	63	60	62

During 1986 both Gatwick and Elmdon recorded similar trends with alternating high and low risk periods, but overall Gatwick produced over 50% more hours than Elmdon.

Historically the 1986 totals appear low, as were the daily totals during the 1985 study (11-20 December). The totals of "condensation hours" should be examined in conjunction with the accumulated temperatures from table 1. During 1981 for example there was a prolonged spell of extremely cold weather with the air temperatures at Elmdon below freezing for several days, and falling at times to -10°C, and -18°C at the coldest. In general there were lengthy periods in every year when the risk of condensation was high.

The amount of water deposited on the skin surface is proportional to the differences between the saturation vapour pressure of the skin surface temperature and the surrounding air dew point temperature. (Monteith and Butler, 1979; Butler, 1980).

3. Effects of Fan Ventilation on Surface Moisture

The need for air circulation around stored poultry meat to overcome the problem of "sweating" has long been recognised in the processing industry. The demand of evaporation from the skin surface induced by this airflow will depend on two parameters.

i. The ability of the air to take up moisture
ii. The rate of flow of air across the skin surface.

Air with low relative humidity, or more precisely a large vapour pressure deficit, will obviously be able to absorb more moisture than air which is near or at 100% humidity. Similarly an increased air flow increases the volume of air passing over the skin surface and thus the potential for evaporation increases.

There are times, however, when ventilating with ambient air will not be advantageous;

i. When the ambient air is warmer than the skin surface.

ii. When the dew point of the incoming air is above the skin surface temperature.

iii. When the ambient air is sufficiently cold to freeze poultry flesh.

A simple differential thermostat will solve the first problem, and in doing so it will also dramatically reduce the incidence of hours under point two. As was described in table 3 condensation is most probable during periods of rising temperature, and this would be excluded from the store by the action of a differential thermostat.

If the period of zero ventilation were to be prolonged, and the evidence from table 4 suggests that in every year there are lengthy periods, then a form of air recirculation would necessary to maintain air movement. Paddle fans or in ducted polythene systems offer economic means to accomplish this.

The remaining problem of particularly low ambient temperatures should be more than apparent to the management and, given a sufficient level of insulation in the store, present little difficulty. If particularly cold weather persists, as during 1981, then a small amount of heat may be required to maintain an optimum storage temperature.

General Conclusions

1. The pre Christmas storage period in the 1985 study was remarkably warm.

2. The risk of spoilage increases with time, but for dry plucked, uneviscerated birds a 10 day storage period will encounter warm weather problems infrequently circa 1 year in 10.

3. Condensation on the skin surface, or "sweating", varies between years and places, but high risk periods are evident every year.

4. Fan ventilation increases the evaporative demand from the skin surface, and will also enhance cooling through latent heat exchanges.

5. A differential thermostat to prevent warm air being drawn into the store will maintain lower store temperatures and also reduce the risk of condensation - but a recirculation system should also be installed.

Acknowledgement

J. A. Karn, ADAS Microbiologist, Reading, contributed the sections on pages 5 and 6 - thank you James.

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Fig.1a. SKIN SURFACE MOISTURE IN STORE ROOM : 23-25 Nov 1986

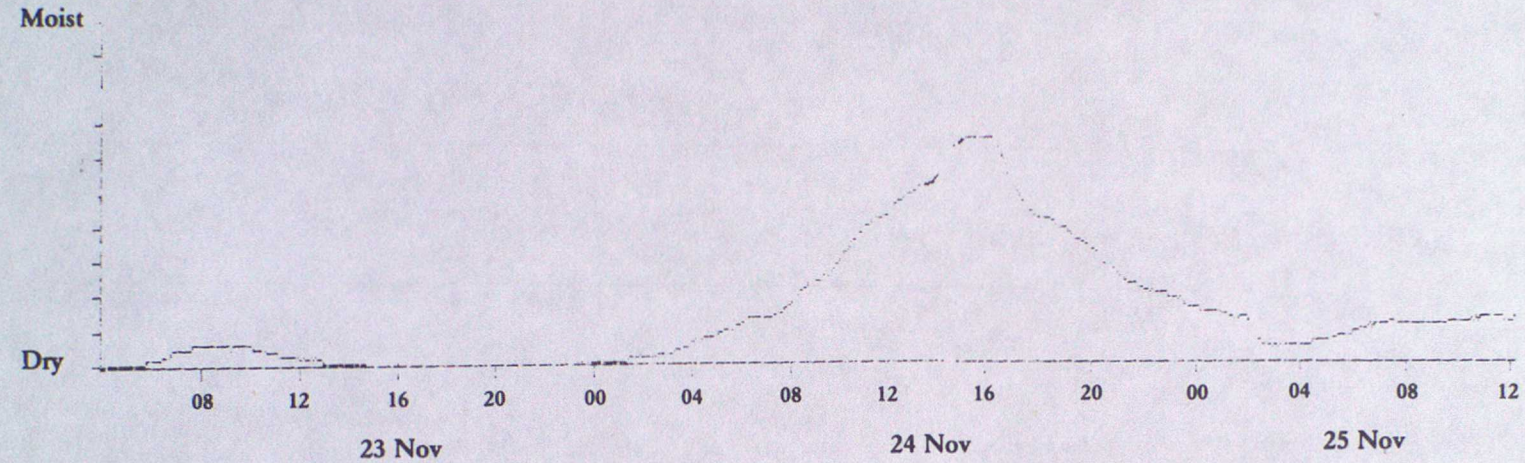


Fig.1b. SKIN SURFACE MOISTURE IN COLD STORE : 28-30 Nov 1986

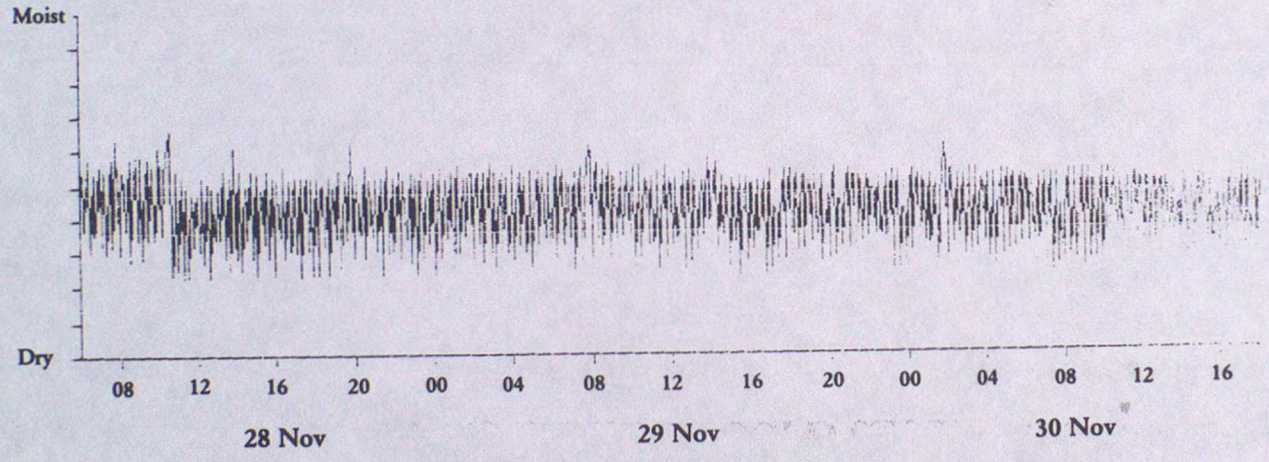
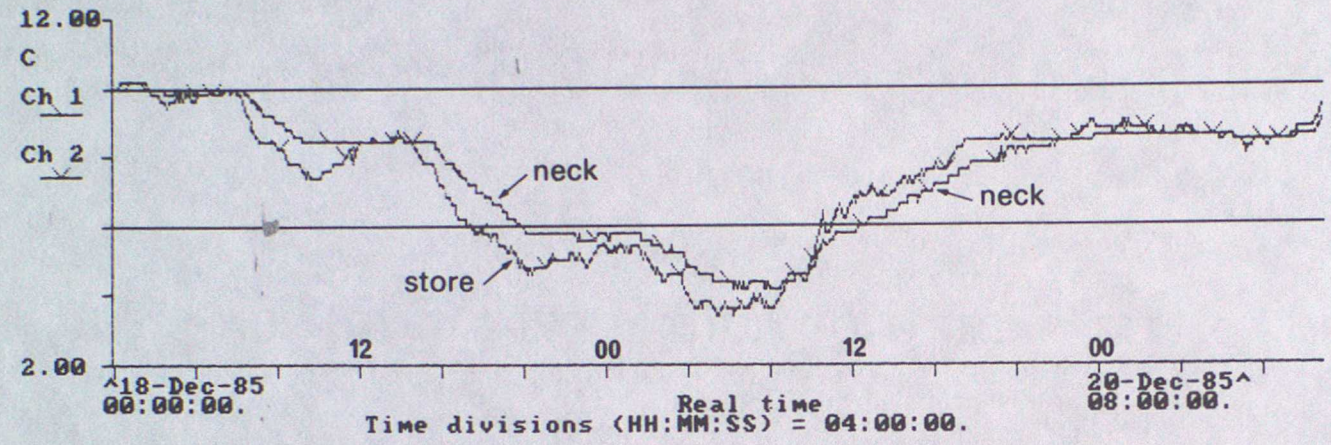
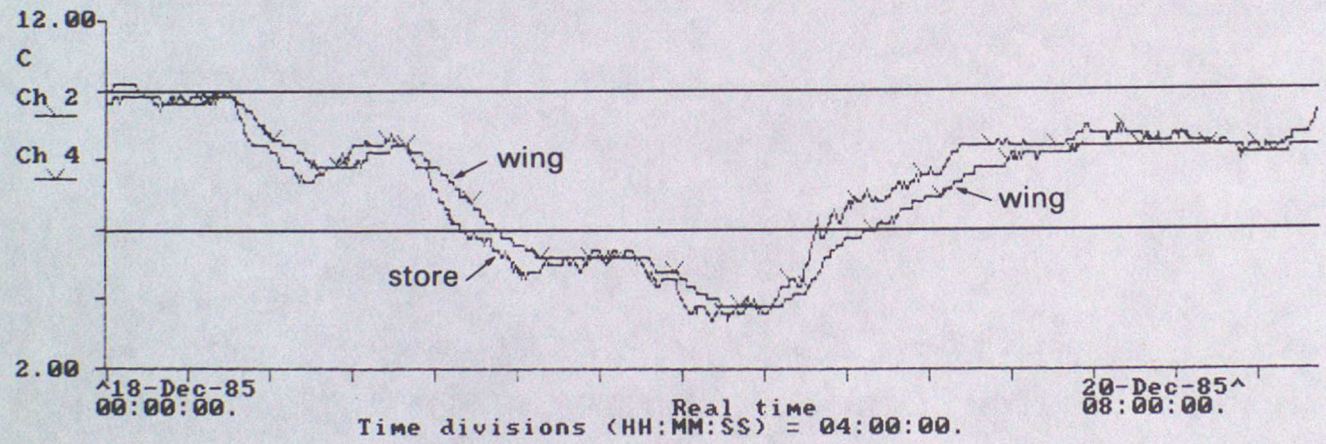


Fig.2

Variation of Turkey Carcase Temperature Against Store Air Temperature





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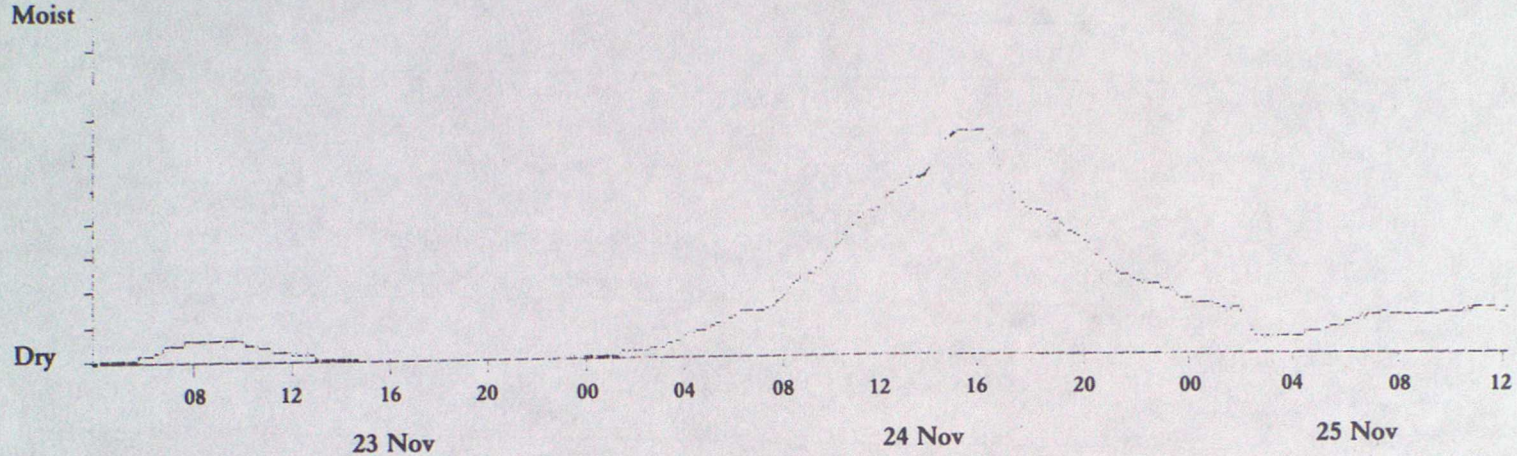
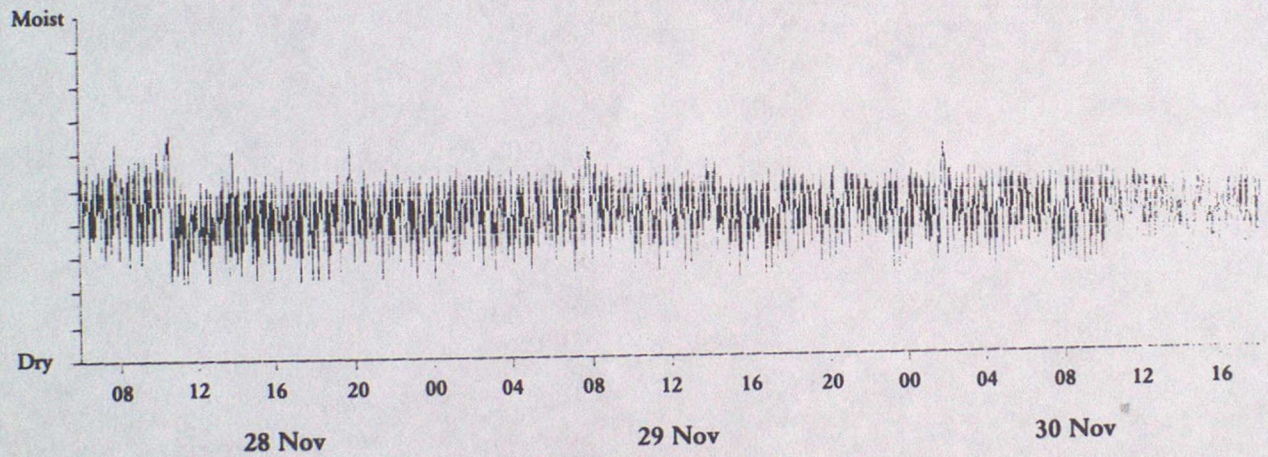


Fig.1b. SKIN SURFACE MOISTURE IN COLD STORE : 28-30 Nov 1986



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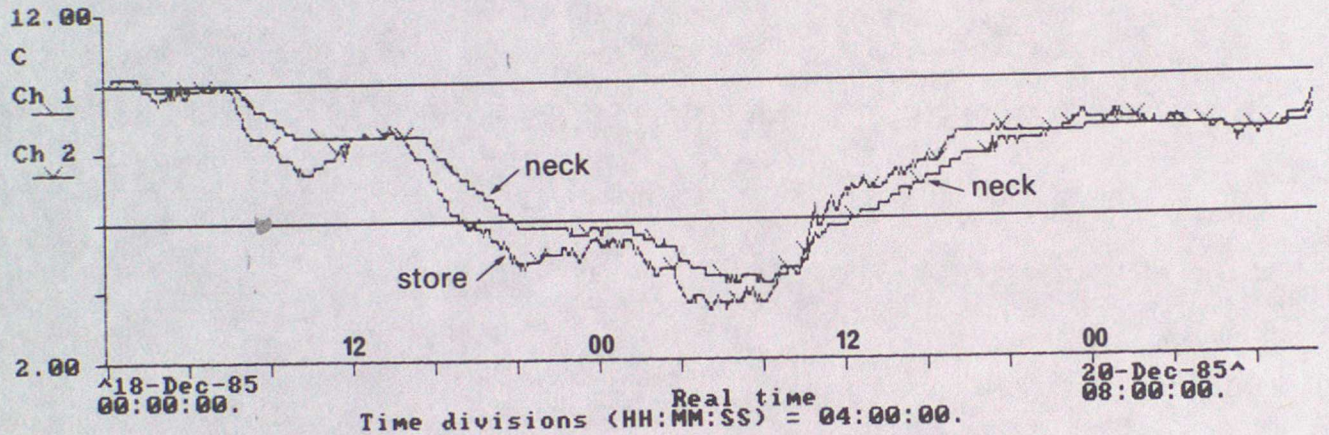
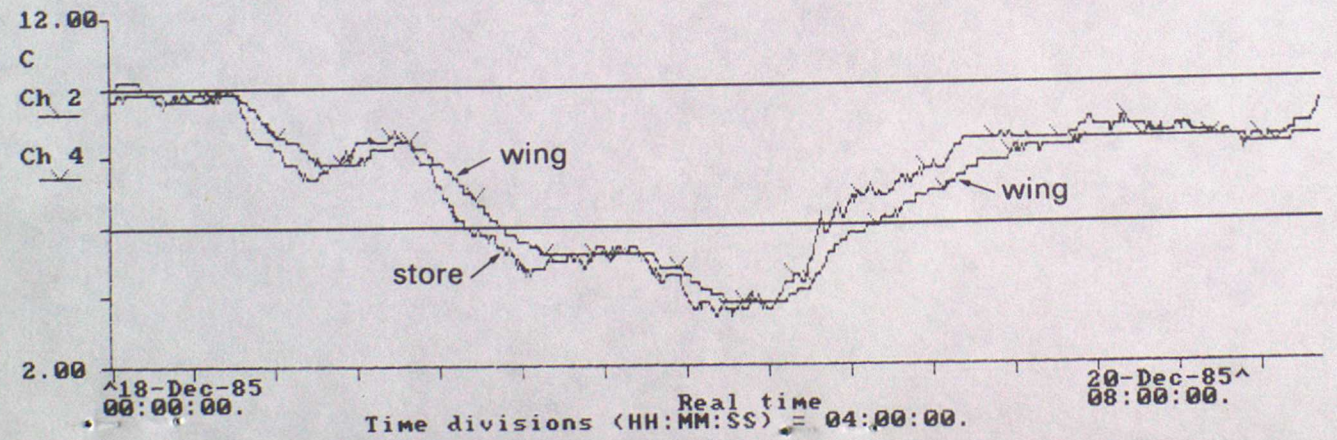
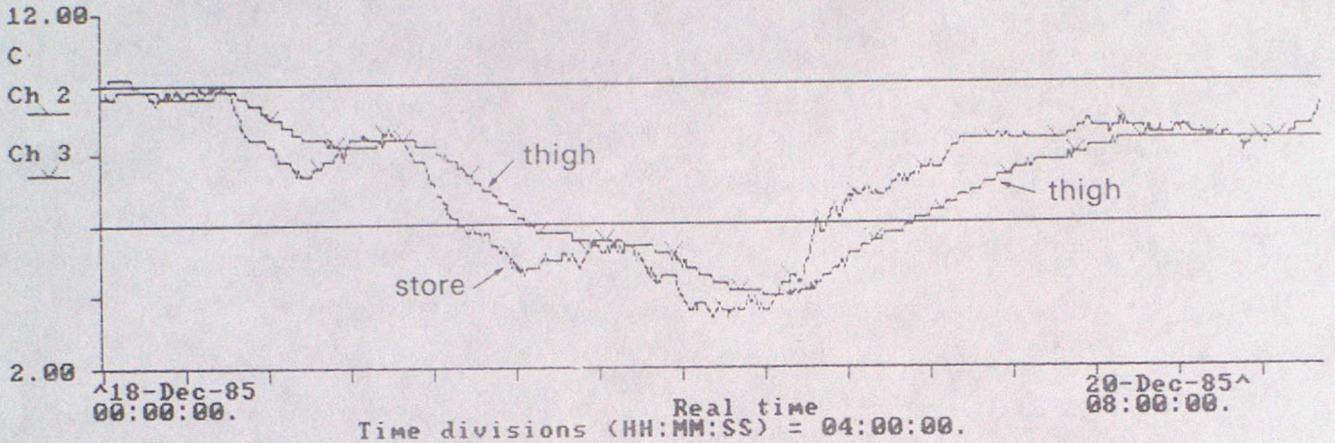
Variation of Turkey Carcase Temperature Against Store Air Temperature



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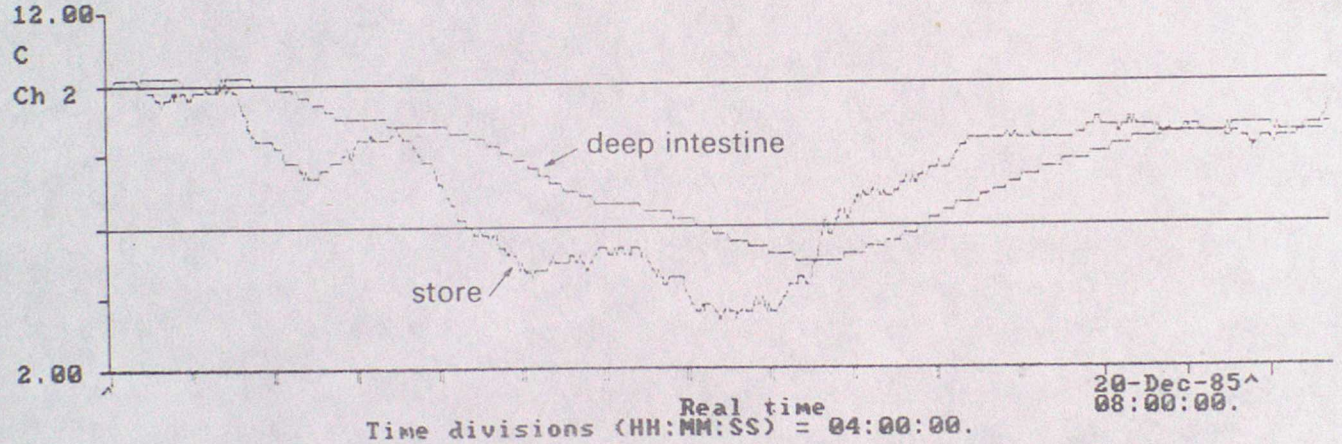
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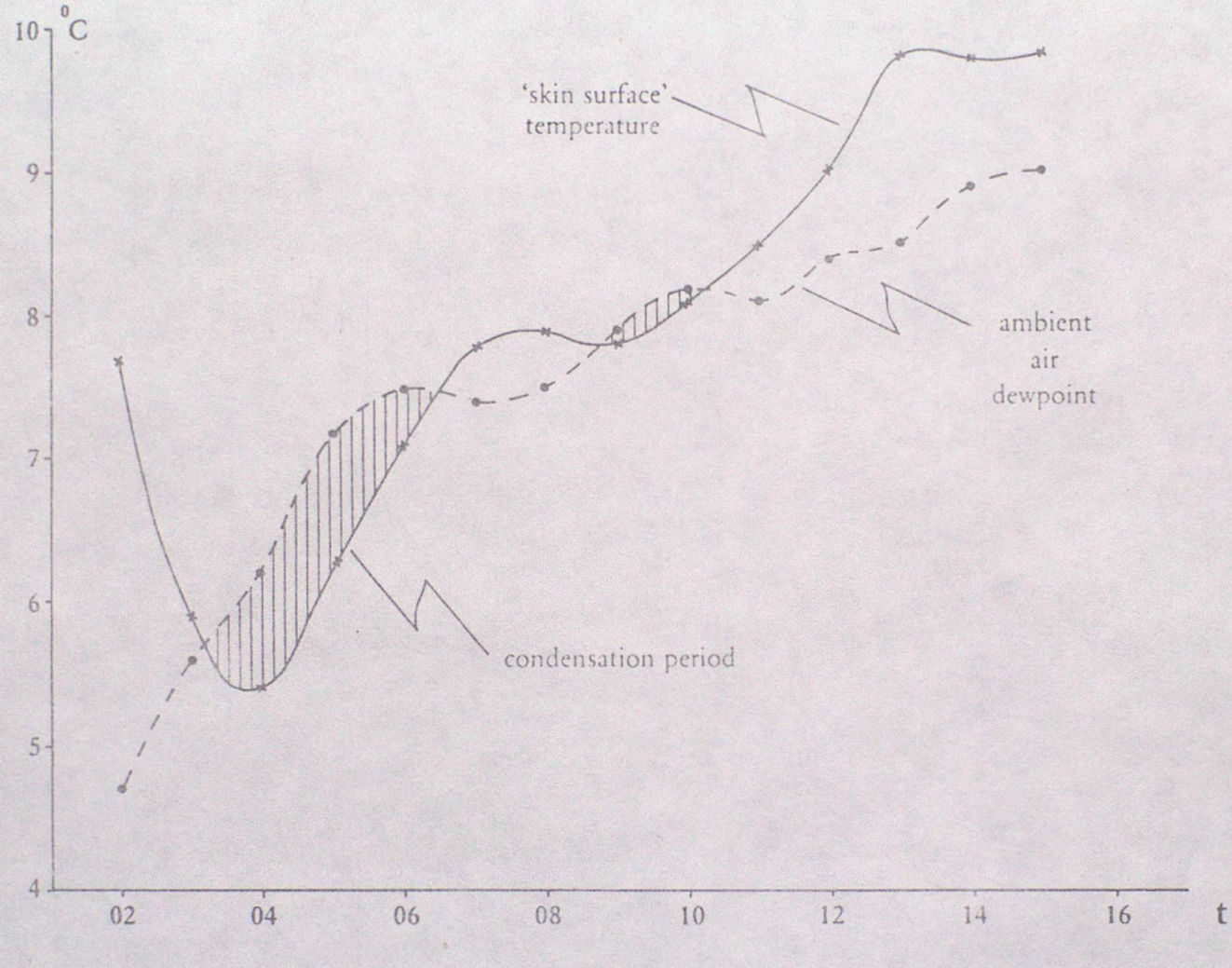
fig. 3

Condensation Risk : Elmdon



1st December 1984